

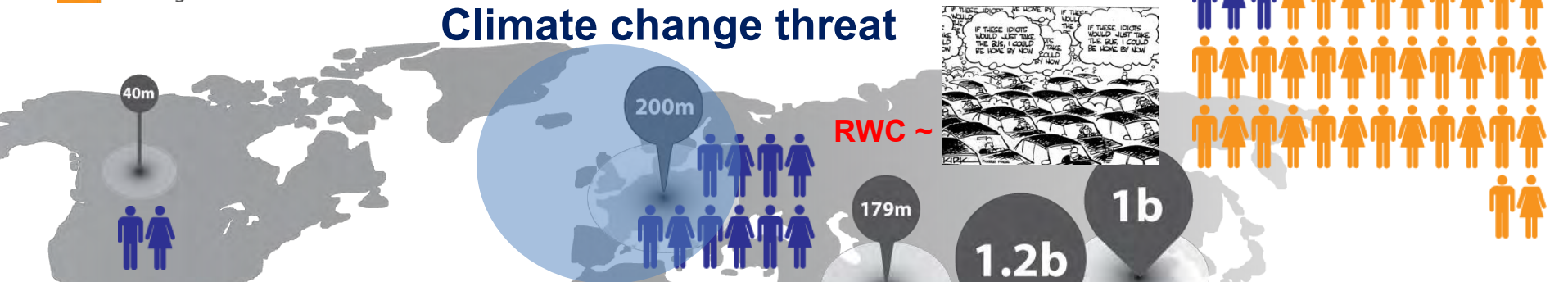
PARTICULATE EMISSIONS FROM RESIDENTIAL WOOD COMBUSTION: IMPROVING ESTIMATIONS IN DENMARK AND PORTUGAL

INTERNATIONAL CONFERENCE ON CARBONACEOUS PARTICLES
BERKELEY, USA

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DANISH BUILDING RESEARCH INSTITUTE
AALBORG UNIVERSITY COPENHAGEN



How to improve PM emission estimations from RWC in Europe?

Over 240 million people is relying on heating fireplaces and inefficient WBSs and boilers in the cold season

Global health risk

- Household heating is a major cause of premature deaths in Europe, North America and China
- **Fireplaces and wood-burning stoves** (WBSs) in more than 20% of the European households
- Secondary heating systems in areas with developed district heating grids

HOUSEHOLD HEATING AND PM EMISSIONS IN WESTERN EUROPE (two case studies and new methods in the EU28)

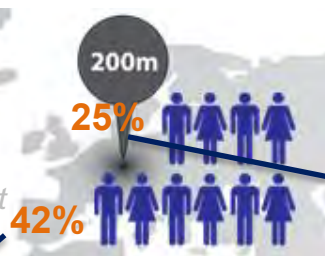
High fuel loads & low tightness

*Heating typical
a single family house
with NG
Costs 10% more
In 2015 than in 2008
(ERSE, 2015)*

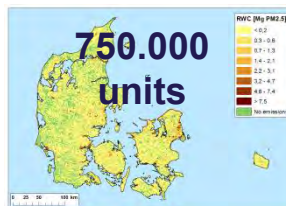


Primary energy supply for heat
(high wattage and natural vent.)

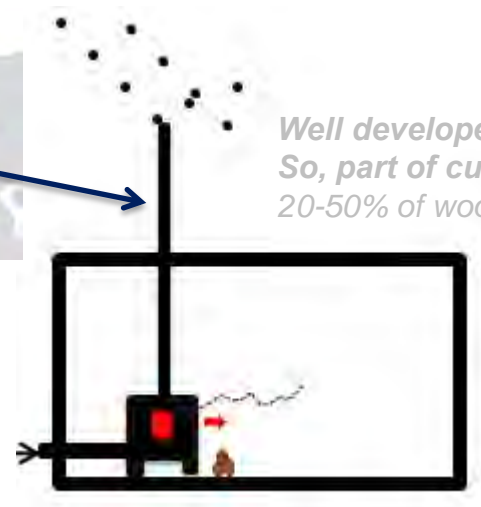
Portugal
10,4 Mo (40% rural)
92.212 km²



42%
RWC units
per dwelling



Low fuel loads & high tightness



*Well developed heating grid
So, part of culture...
20-50% of wood heat*

Secondary energy for cozyness
(low wattage and mechanical vent.)

Denmark
+ 5,6 Mo (12% rural) =
42.916 km²
43% of people (<10% rural)
32% of area
(of California)

OLD TRADITIONAL WBSs

*Fireplace in Europe
Open fire, 2014*

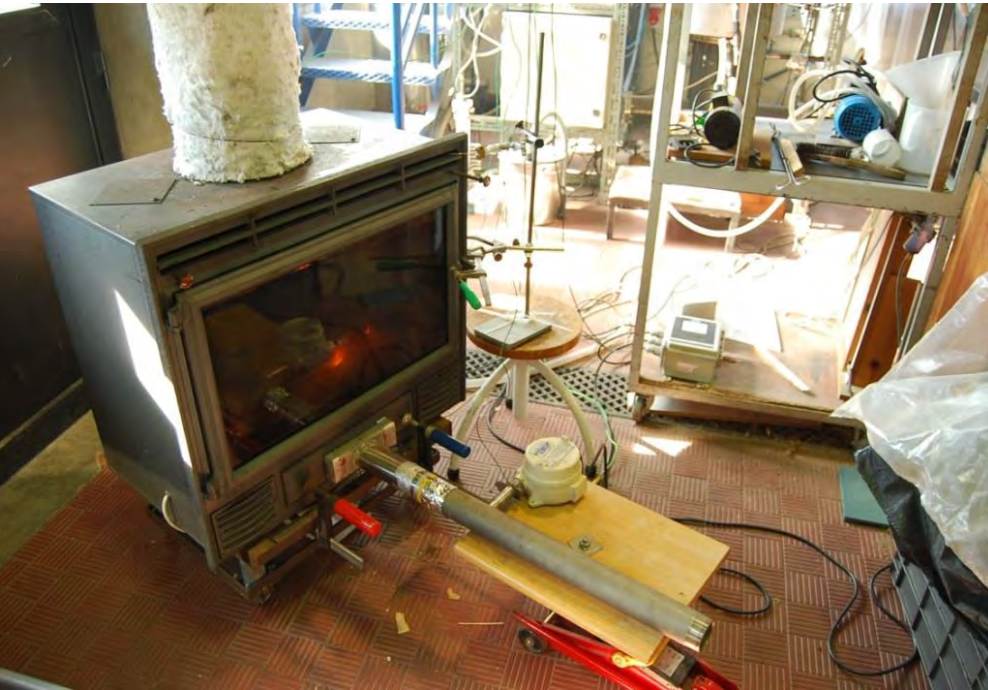


*Closed stove in Spain
Carvalho, 2015*



NEW & NEW MODERN WBS

*Wood stove (NEW, before 2008) in Portugal
Carvalho, 2014*



*Swan labelled stove (NEW MODERN, after 2008) in Denmark
Carvalho, 2014*



BOILERS AND COOKERS

*Residential wood boiler in Denmark
Perthshire biofuels, 2015*

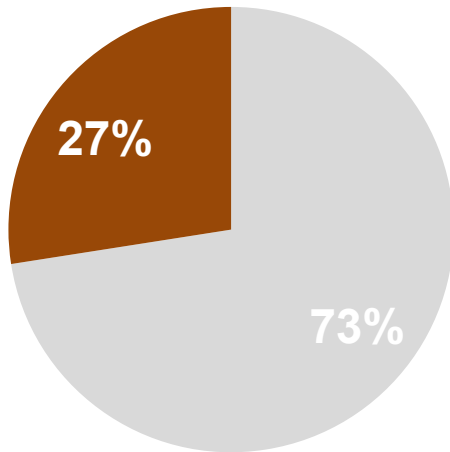


*Wood cooking boiler in Portugal
Lareiras Pacinha , 2015*

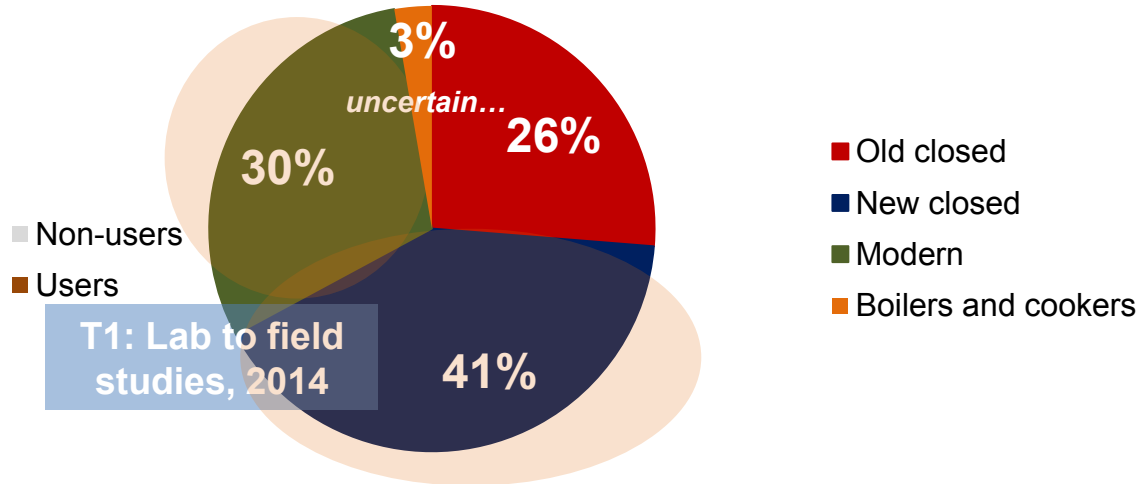


RWC in Denmark/Nordic region

~1.6Mo users
per ~3.0Mo dwellings



~770,850 installations
21.920 TJ

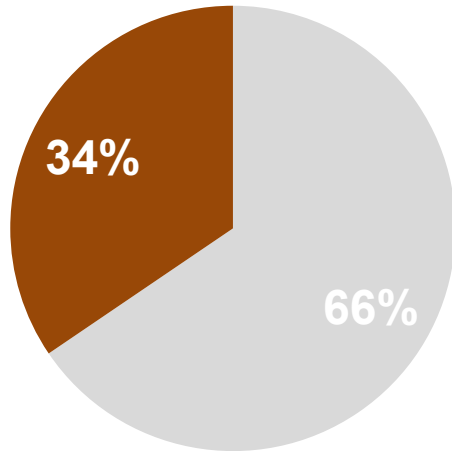


[12] Incentive and Forced Technology. Danish Ministry of Environment. Virkemiddelkatalog for NOX, PM2.5, NMVOC og NH3, Miljøprojekt nr. 1514, 2013.

[13] Forced Technology. Brændeforbrug i Danmark 2013.

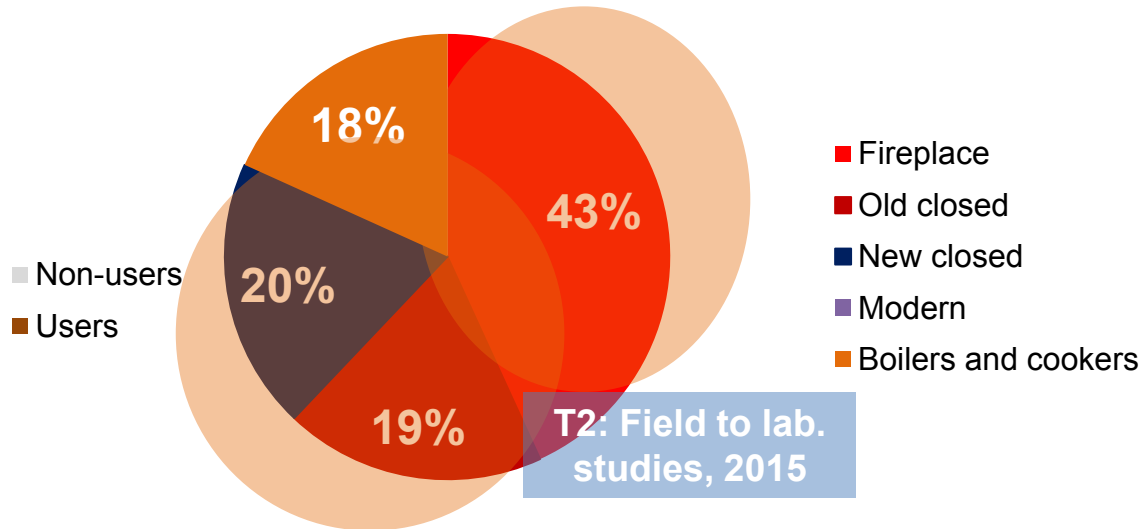
RWC in Portugal/Mediterran region

~3.6 Mo users
Over ~3.4Mo dwellings



~1.2Mo installations

35.342 TJ **+60% than DK!**



[1] C. Gonçalves, C. Alves, C. Pio. Inventory of fine particulate organic compound emissions from residential wood combustion in Portugal. Atmospheric Environment, 50, 297-306, 2012.

[14] Instituto Nacional de Estatística. Housing units of usual residence (No.) by Geographic localization (at the date of Census 2001) and Sewal disposal system; Decennialin Portugal, 2001.

AVAILABLE EMISSION INVENTORIES AND GAPS (PHONE SURVEYS)

$$E_{PM} = \sum_{i=0}^n W_C \cdot EF_S$$

Denmark

- Survey (2015) for ONLY 2133 people and 4 types of stoves...
- Average Efs on condensed particles with a controlled pressure chimney draft (Norwegian method)
- Spatial distribution from housing registration system (BBR)

Portugal

- Survey (2012) for ONLY 2400 people and 2 types of systems...
- Standard Efs on condensed particles but with uncontrolled pressure chimney draft (prEN4711)
- Spatial distribution from one single study [1]

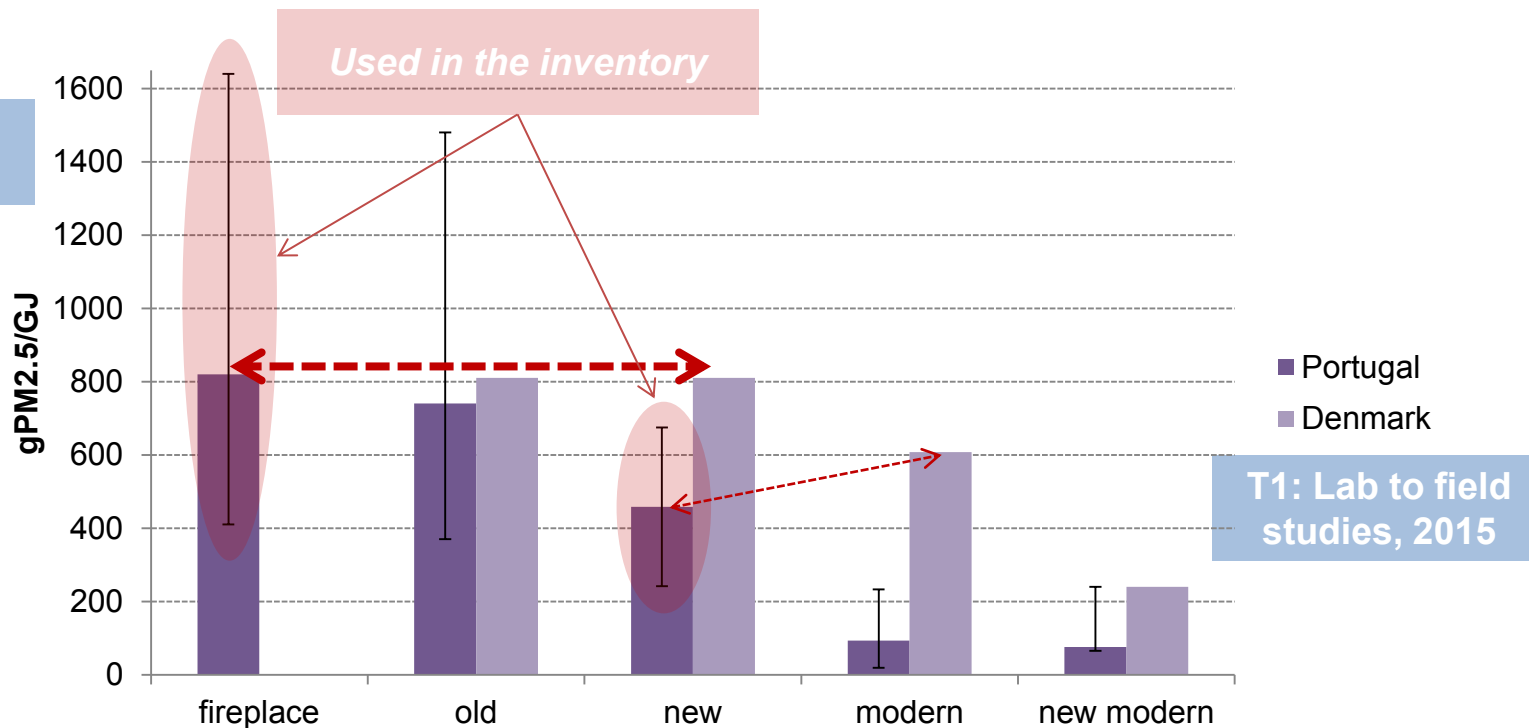
[2] O. K. Nielsen, M. S. Plejdrup, M. Winther, M. H. Mikkelsen, M. Nielsen, S. Gyldenkærne, P. Fauser, R. Albrektsen, K. Hjelgaard, H. G. Bruun, M. Thomsen. Annual Danish Annual Inventory report to UNECE, 2015.

[1] C. Gonçalves, C. Alves, C. Pio. Inventory of fine particulate organic compound emissions from residential wood combustion in Portugal. Atmospheric Environment, 50, 297-306, 2012.

DANISH VS. PORTUGUESE PM2.5 EMISSION FACTORS? (FIREPLACES, WOOD-LOG AND PELLET STOVES)

T2: Lab to field studies, 2014

$$E_{PM} = \sum_{i=0}^n W_{ci} \cdot EF_{si}$$



[12] Incentive, Forced Technology. Danish Ministry of Environment. [1] C. Gonçalves, C. Alves, C. Pio. Inventory of fine particulate organic compound emissions from residential wood combustion in Portugal. Virkemiddelkatalog for NOX, PM2.5, NMVOC og NH3, Miljøprojekt nr. 1514, 2013.

[18] EMEP, 2013

MAIN GAPS ON OFFICIAL EMISSION FACTORS?

$$E_{PM} = \sum_{i=0}^n W_C \cdot EFs$$

- **Wet wood used in real-life NOT CONSIDERED...**
- **Typical fuel loads vary from mean values...**

Denmark

- Approaches to mainstream emissions, not representing:
 - Uncontrolled stove venting and household ventilation (underpressure in real world)?

Portugal

- Lab tests under ideal conditions do not represent situations where:
 - Uncontrolled stove venting and household ventilation (under or over pressure in real world)?

[2] O. K. Nielsen, M. S. Plejdrup, M. Winther, M. H. Mikkelsen, M. Nielsen, S. Gyldenkærne, P. Fauser, R. Albrektsen, K. Hjelgaard, H. G. Bruun, M. Thomsen. Annual Danish Annual Inventory report to UNECE, 2015.

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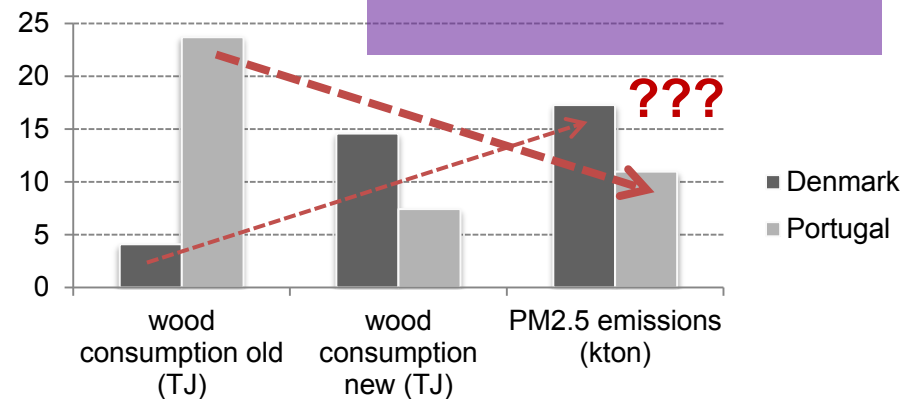
RECALCULATIONS OF ANNUAL PM2.5 EMISSIONS?

$$E_{PM} = \sum_{i=0}^n W_c \cdot EF_s$$

Underestimated emissions
for Portuguese fireplaces?

Overestimated emissions
for new Danish stoves?

PM2.5 emissions	kton PM2.5 year-1	kg PM2.5 per capita	kton PM2.5 year-1	Share
Countries	RWC	RWC	All sources	%
Denmark	17,3?	3,1?	28,3	61%?
Portugal	11,0?	1,1	36,3	30%?

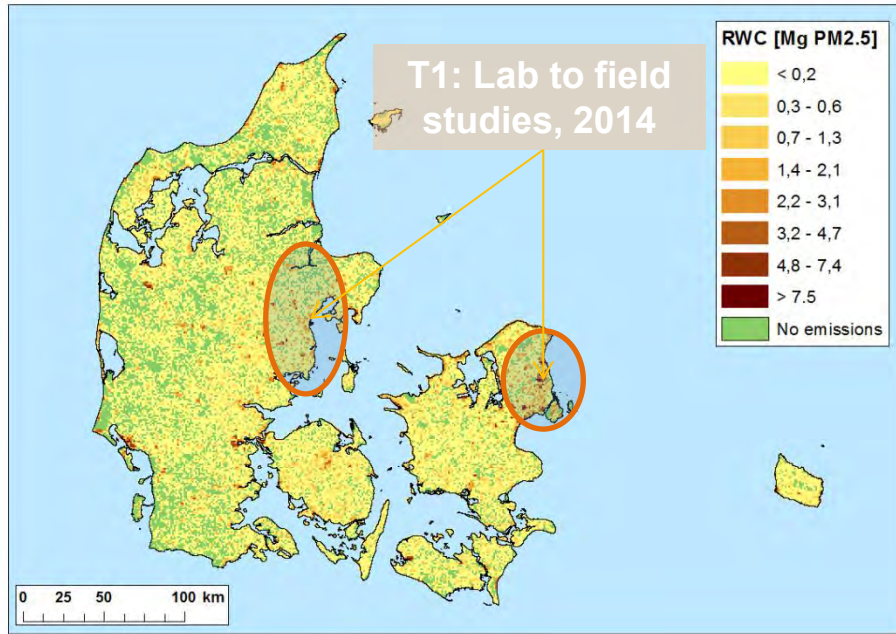


[2] O. K. Nielsen, M. S. Plejdrup, M. Winther, M. H. Mikkelsen, M. Nielsen, S. Gyldenkærne, P. Fauser, R. Albrechtsen, K. Hjelgaard, H. G. Bruun, M. Thomsen. Annual Danish Annual Inventory report to UNECE, 2015.

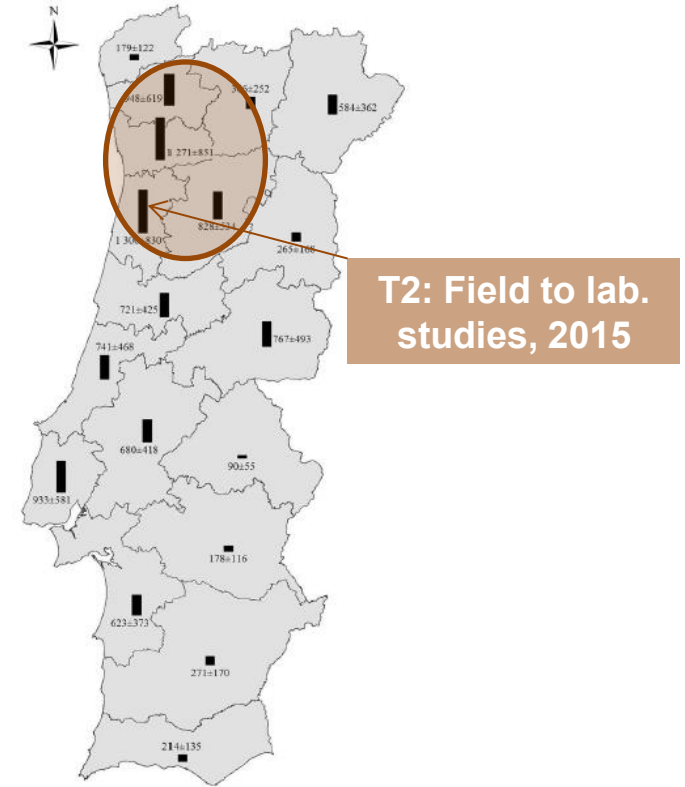
[1] C. Gonçalves, C. Alves, C. Pio. Inventory of fine particulate organic compound emissions from residential wood combustion in Portugal. Atmospheric Environment, 50, 297-306, 2012.

SPATIAL DISTRIBUTION OF PM_{2.5} EMISSIONS PER CASE

$$E_{PM} = \sum_{i=0}^n W_c \cdot EF_s$$



[15] Plejdrup, M.S., Nielsen, O-K. & Brandt, J., 2015: Development of a model for high resolution spatial distribution of emissions from residential wood combustion in Denmark. In prep.

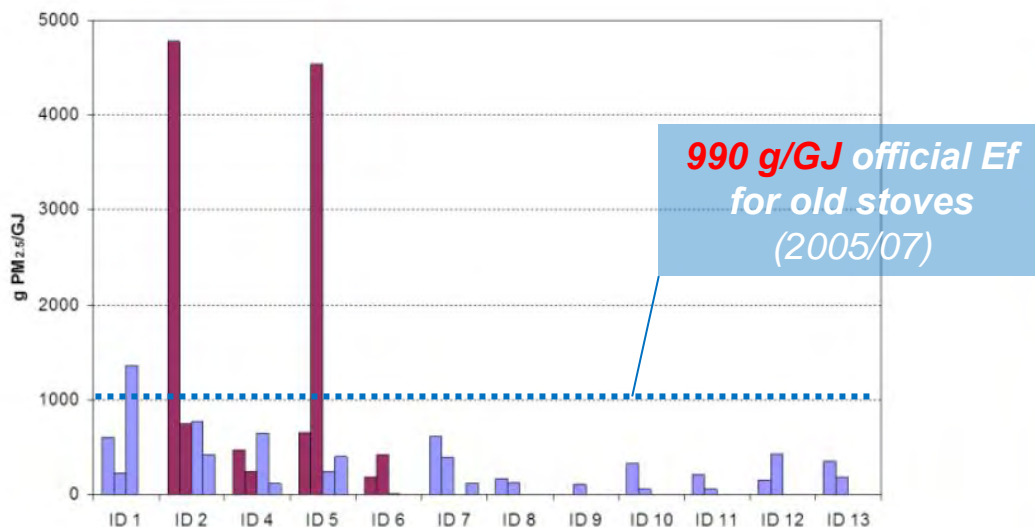


[1] C. Gonçalves, C. Alves, C. Pio. Inventory of fine particulate organic compound emissions from residential wood combustion in Portugal. Atmospheric Environment, 50, 297-306, 2012.

T1a. A PIONEER LAB-TO-FIELD TEST ON EFs IN DANISH DWELLINGS (by Glausius et al., DCE, Aarhus University, 2005)

[7] Glausius et al. 2005

(real-life measurements in 13 houses in Denmark)



**Users behaviours can be the main reason
of variations on the PM_{2.5} Efs!**



[16] J. Illerup, T. Henriksen, T. Brændeovne og små kedler partikelemissioner og reduktionstiltag, 2007 (official laboratory tests)

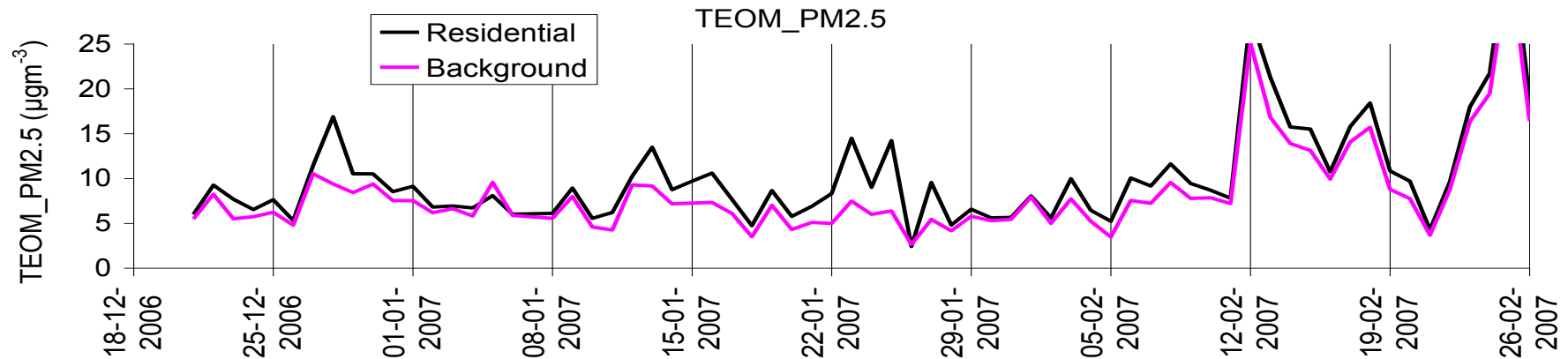
T1b: LAB-TO-FIELD AIR QUALITY STUDY IN A DANISH VILLAGE (WOODUSE, DCE, Aarhus University, 2006/12)



WOODUSE: Slagslunde: 400 houses, 201 with wood stoves or boilers

[4] H.R. Olesen, P. Wåhlin, J. Illerup et al. Characteristics of residential wood combustion – results from a Danish case study, 2012
(experiments carried out in 2006/07)

T1b: TEOM measured [PM_{2.5}] increment due to wood combustion during the 6-weeks period



[4] H.R. Olesen, P. Wåhlin, J. Illerup et al. Characteristics of residential wood combustion – results from a Danish case study, 2012
(experiments carried out in 2006/07)

TEOM (tapered element oscillating microbalance) is a continuous measurement method of atmospheric particles

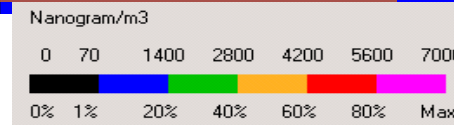
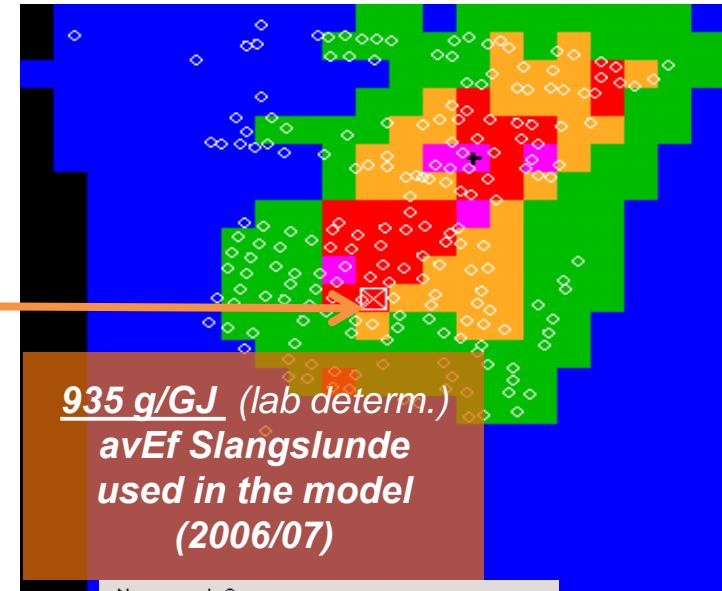
T1: WOODUSE computed increment due to wood combustion for an average for 6-week period



Average at the monitor:

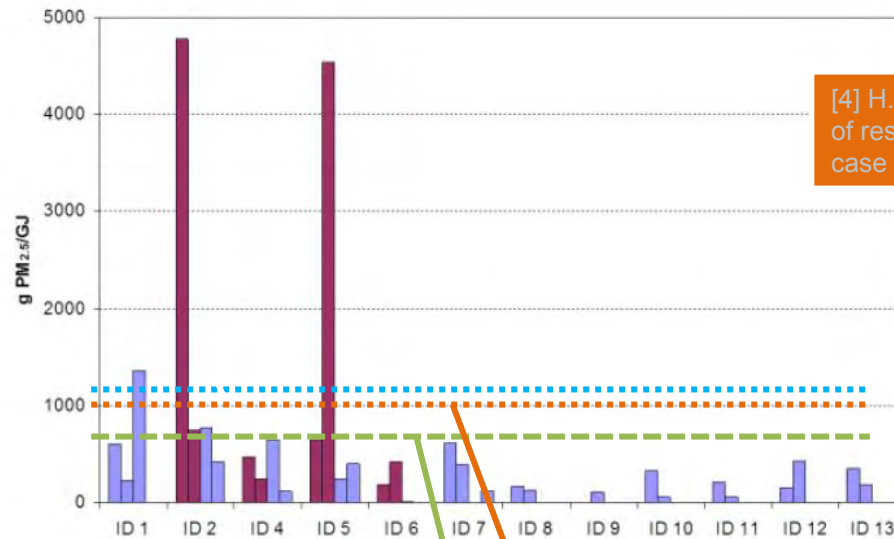
Measured: 1.97 µg/m³

Modelled (OML): 4.2 µg/m³



$$\text{correction factor} = \frac{[\text{measured}]_{av}}{[\text{modelled}]_{av}} = \frac{[1.97]_{av}}{[4.2]_{av}} = 0.47$$

T1b WOODUSE: LAB-TO-FIELD AIR QUALITY STUDY IN A DANISH VILLAGE (DCE, , Aarhus University, 2007/12)



[4] H.R. Olesen, P. Wählin, J. Illerup et al. Characteristics of residential wood combustion – results from a Danish case study, 2012 (experiments carried out in 2006/07)

$$\text{corr. av. EF} = 0.47 \cdot 935 \sim 440 \text{ gPM/GJ}$$

T2: FIELD-TO-LAB IN PORTUGAL: performance test installation (CESAM, Aveiro University, 2015)

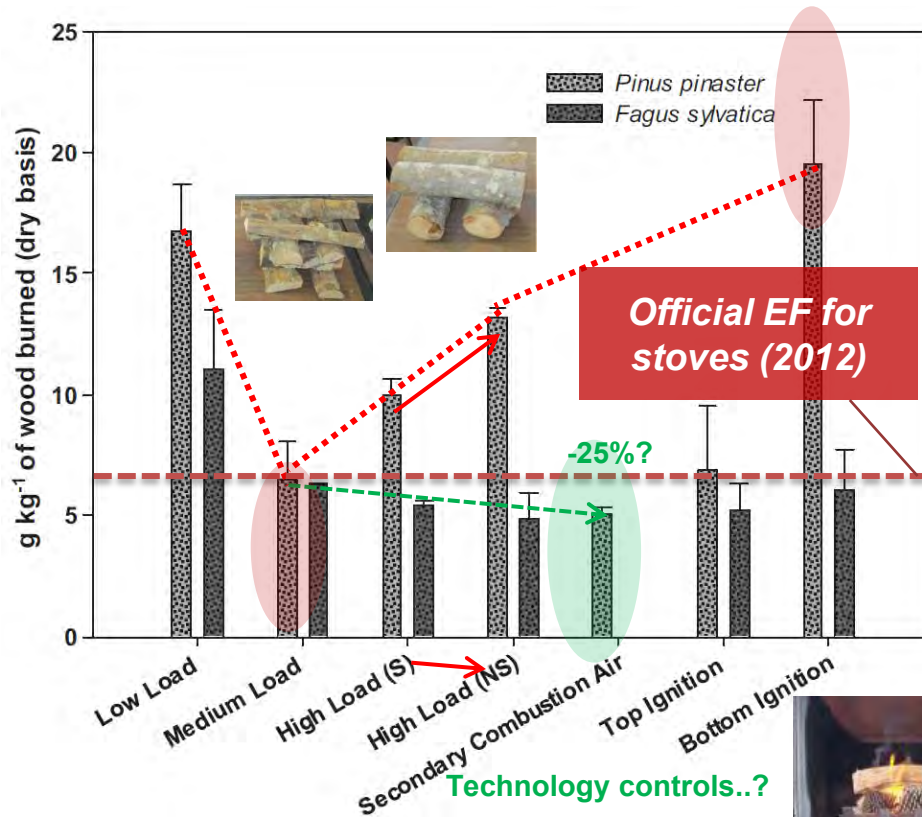
Dilution tunnel and dust-track

Testing convection installation



[5] E.D. Vicente, M.A. Duarte, A.I. Calvo, T.F. Nunes, L. Tarelho, C.A. Alves. Emission of carbon monoxide, total hydrocarbons and particulate matter during wood combustion in a stove operating under distinct conditions, 2015.

T2: A NEW FIELD-TO-LAB APPROACH FOR AN IBERIAN WBSs (CESAM, Aveiro University, 2015)



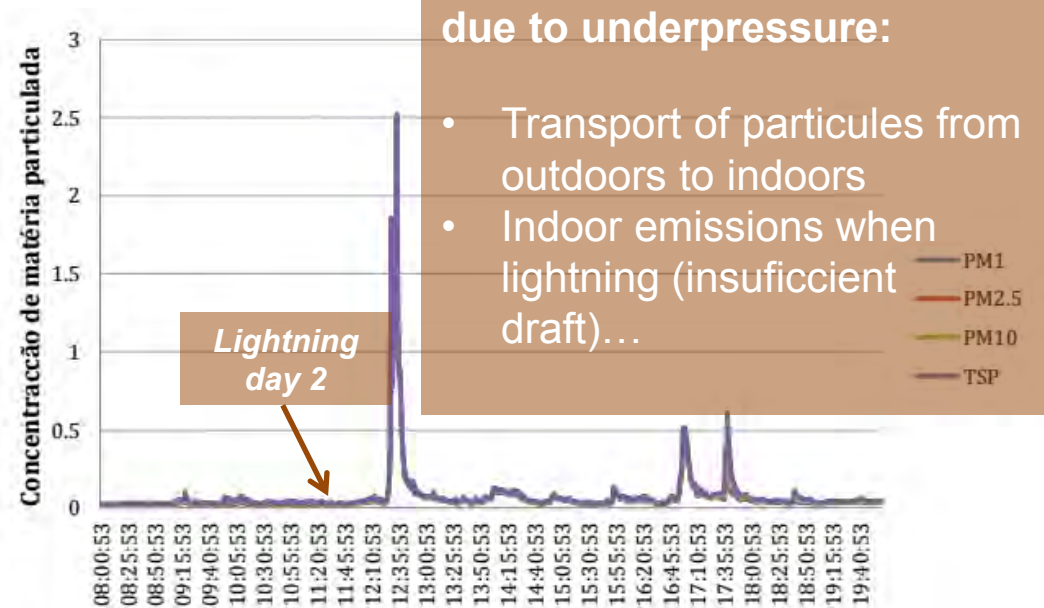
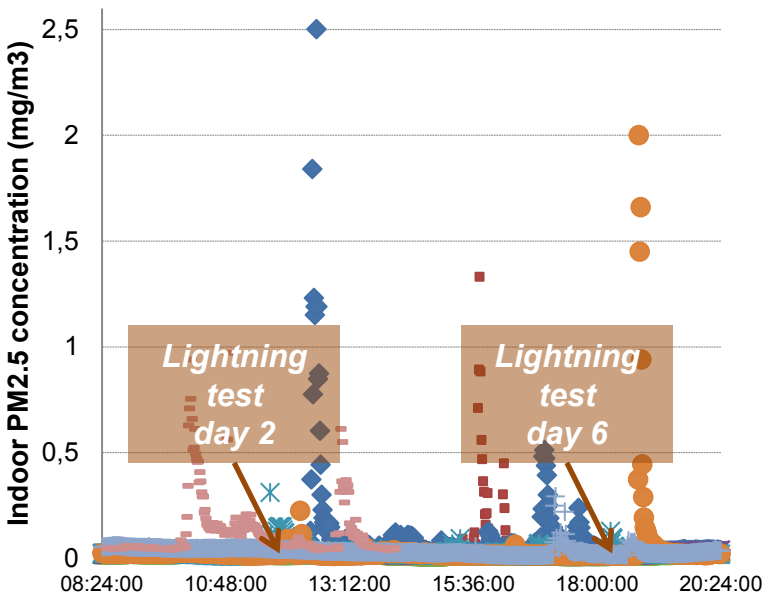
For the dry softwood *Pinus Pinaster* (wood type on RWC in **Portugal**):

- Variations on fuel load may increase particulate emissions by more than 3 times comparing to official emission factors used in previous inventories "**5.2±4.3 g/kgF**"
- These variations might be even larger if we consider a common bottom ignition during lightning!

For the dry hardwood *Fagus Sylvatica* (typical fuel in **Spain**):

- Such operating practices did not change significantly...

IAQ TEST: indoor [PM_{2.5}] during one week in the Autumn when testing a wood stove (*CESAM, Aveiro University, 2014*)



Conclusions and recommendations

- The current estimations are rather uncertain due to:
 - Few available surveys with few respondents...
 - **Little knowledge of representative Efs...**
 - Limited knowledge on the spatial distribution...
- Improve activity data in conjunction with national chimney sweepers associations
- New testing methods and studies to determine real emissions, especially for old types of appliances (larger uncertainties) by:
 - Bringing the lab to field (quite expensive...)
 - Bringing the field to lab** (economic, deep investigation on burning practices)
 - Modelling real-life household** savings and mitigation effects

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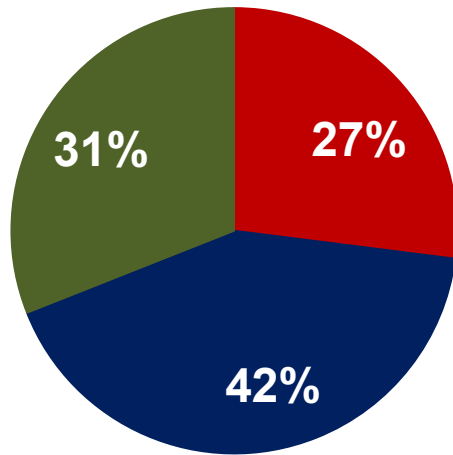
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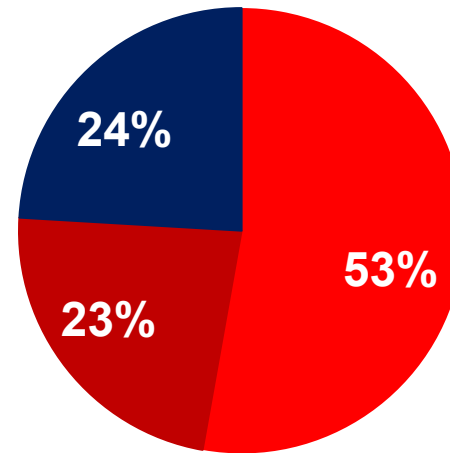
WBS use in Denmark and Portugal

21.920 TJ



Denmark

35.342 TJ



Portugal

[2] O. K. Nielsen, M. S. Plejdrup, M. Winther, M. H. Mikkelsen, M. Nielsen, S. Gyldenkærne, P. Fauser, R. Albrektsen, K. Hjelgaard, H. G. Bruun, M. Thomsen. Annual Danish Annual Inventory report to UNECE, 2015.

[1] C. Gonçalves, C. Alves, C. Pio. Inventory of fine particulate organic compound emissions from residential wood combustion in Portugal. Atmospheric Environment, 50, 297-306, 2012.

SURVEYS (2012/13): REAL WOOD CONSUMPTION AND TRANSITIONS (T)?

$$E_{PM} = \sum_{i=0}^n Wci \cdot EFsi$$

T1: Lab to field studies, 2014

RWC	Activity data	Respondents	Dwellings Per pop.	Stoves	Share	Users or Per cap.	Old stoves (before 2008)		New stoves (after 2008)		WBSs	Boilers and cookers	Ref.
Countries	All	All	All	All	All	Users	Fireplace	Old closed	New closed	Modern	All	All	All
Denmark 2013	Number (Mo)	2.133 x10 ⁻³	(3,0/10,4) x10 ⁶	0,8x10 ⁶	27%	1,5x10 ⁶	-	202.500	315.000	232.500	750.000	20.845	[9] Forced tech, 2013 [2] Nielsen, 2015
	Wood consump. (TJ y-1)	-	-	21.920		3.9	-	4.087	8.622	5.936	18.645	3.275	
Portugal 2012	Number (Mo)	2.387	(3,4/5,6) x10 ⁶	1.5x10 ⁶	34%	3,6x10 ⁶	645.818	282.903	294.333	-	1.161.221	272.901	[1] Goncalves, 2012 [10] INE, 2011
	Wood consump. (TJ y-1)	-	-	35.342		3.6	17.184	6.512	7.410	-	31.105	4.237	

T2: field to lab studies, 2015